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ABSTRACT

Recently, it was proposed that a curricular aim of science education should be to engender an understanding of the nature of the scientific enterprise among students, as well as a knowledge of the technical contents of science. Seven diagnostic instruments were designed and administered to students (between the ages of 9 and 16) in an effort to investigate students' representations of the scientific enterprise. Specifically, researchers tried to determine in which domains do students think scientists attempt to explain, and on what basis do they think that scientists make knowledge claims. Students were asked to respond to the following questions: (1) Which kind of fabric is waterproof?; (2) Which is the best program on TV?; (3) Is it wrong to keep dolphins in captivity?; (4) How do birds find their way over long distances?; (5) What diet is best to keep babies healthy?; (6) Is it cheaper to buy a large or a small packet of washing powder?; (7) How was the Earth made?; (8) Is the Earth's atmosphere heating up?; (9) Do ghosts haunt old houses at night?; (10) What kind of bacteria are in the water supply?; and (11) Can any metal be made into a magnet? (ZWH)

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ED 368 545

Progression in learning about 'the nature of science': issues of conceptualisation and methodology

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This paper describes a study on progression of young people's understandings of 'the nature of science' from age 9 to age 16. The paper aims to problematise the notion of 'progression in learning', and to describe the methodology used in the study in the context of a range of possible methodologies to study progression in learning science. Uses and limitations in the uses for data from cross-sectional studies on progression are discussed.

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Introduction

In studies which address students' learning of science it is important to be clear about the nature of the subject matter to be learnt. For example, science educators have talked about young people needing to know about the technical contents of science (e.g. Thomas and Durant, 1987), the purposes of scientific knowledge (e.g. Giere, 1991), the extent to which particular theories are validated and accepted within scientific communities (Duschl, 1990), and the processes by which knowledge is validated within scientific communities (e.g. Miller, 1983).

The epistemology of scientific knowledge and the social processes involved in the generation and validation of this knowledge is a subject of debate, and there are major literatures addressing these issues in the history, philosophy and sociology of science. This is not the place for a review of these literatures and their implications for science education, though it is worth considering some issues relating to the nature and purposes of the scientific knowledge to be taught and learnt through the school science curriculum.

A common image of scientific knowledge and the scientific enterprise presented through the school science curriculum is a *naive inductivist* view: the basis for scientific knowledge is impartial observation of the natural world, followed by induction from a large number of observations to a general rule. The following representation is taken from a publication aimed at science teachers at the secondary school level (NCC, 1993):

> *Scientific literacy is an essential capability for an educated young person. Newspapers, television and magazines, for example, call on knowledge of the function of machines and electrical devices, the effects of chemicals and drugs, the nutritional value of foods, the ecology of different parts of the world and the ethics of transplant surgery and genetics. Part of this literacy is the ability to seek out explanations for things. Pupils need to use their skills to devise ways of testing their ideas and the ideas of others, such as advertising claims, and to evaluate possible solutions to problems.*
>
> *p.4*

The image of the scientific enterprise presented is of *individuals* seeking explanations through a process of *empirical testing* and evaluation. This empiricist, individualist view of scientific knowledge and the scientific enterprise has been heavily criticised in the philosophy of science on several grounds: (i) it is not possible to collect data in a value free way: observations are always made in the context of theory (Popper, 1969); (ii) the logic involved in proving an inductive knowledge claim itself relies on induction (Hume, quoted in Chalmers, 1982); the scientific enterprise is social rather than individual (Kuhn, 1962).

Although there are a range of contemporary perspectives on the nature of scientific knowledge and the workings of scientific communities, these perspectives do appear to share some basic features. For example, scientific knowledge is viewed as *conjectural*: it does not emerge from data as a result of unbiased observation and logical thought, but rather is *created* by people to explain data. Scientific knowledge becomes *public knowledge* as a result of social processes within scientific communities, rather than individual processes. Caution must be exercised, however, in suggesting that there is one 'nature of science' - scientific knowledge and practice are located in different contexts, where different norms may operate (Parushnikova, 1992).

Kuhn (1962) has illustrated the social context of scientific activity by describing episodes in the history of science where scientists work within paradigms of contemporary thought and activity. Theory change does not take place on *empirical* grounds alone; particular *social* conditions are also necessary. Once scientific knowledge is consensually agreed amongst groups of scientists, it can be written down and used to make predictions that may not be empirically testable for a

long period of time (e.g. Chalmers, 1982).

Recent debates in science studies relate to the status of the knowledge produced by scientific communities, and in particular whether that knowledge is warranted by social or empirical processes. Several studies in the history and sociology of science portray the knowledge which emerges as a result of scientific activity as solely the result of social processes (e.g. Latour and Woolgar, 1979). This relativist position argues that there is no basis for knowledge to be a true reflection of the world, and therefore the idea of scientific knowledge progressing towards 'truth' is problematic. Rationalist traditions in the philosophy of science do not accept this position, arguing that although scientific knowledge can never be a true reflection of the world, there are rational ways in which the products of scientific communities can be evaluated.

In arguing for a 'modest realist' ontology, Harré (1986) accepts that our theories about the 'real' world are different from the world: they are different in both epistemology and ontology. For example, a 'theoretical' pendulum consisting of a point mass bob attached to a zero mass chord swinging without friction is clearly different from the 'real' pendula that are being modelled.

One purpose of the scientific enterprise is to produce internally and logically consistent knowledge, generalisable across as wide a range of phenomena as possible. The knowledge produced is, however, produced in particular institutional settings with particular purposes in mind (e.g. Latour and Woolgar, 1979). The 'everyday knowledge' used by individuals in their social and physical interactions is not, however, intended to be internally and logically consistent, nor to be generalisable in the way that scientific knowledge is.

This presents a number of questions to science educators exploring people's learning of science: what representations of scientific knowledge do learners of science bring to their learning? How does this influence their learning of science concepts? How do their images of scientific knowledge and the scientific enterprise itself change as a result of studying science? This study was designed to investigate the nature of students' representations of science in the age range 9 to 16, and to identify any progression in these representations. In the next section, a rationale for our interest in young people's understanding of 'the nature of science' is presented. We go on to describe methodological considerations in eliciting students' representations, and illustrate this by presenting results from one diagnostic instrument. The final part of the paper considers the notion of 'progression' in more general terms, and how data from cross-sectional studies can be used in particular educational contexts.

Focus of the study on young people's understanding of 'the nature of science'

In recent years it has been proposed that a curricular aim of science education should be to engender an understanding of the nature of the scientific enterprise amongst students, as well as a knowledge of the technical contents of science (eg. AAAS, 1989). In addition, it has been suggested that an ability to think about the nature of theories and their relationship to evidence may help students in learning about particular scientific concepts (Driver and Oldham, 1985; Solomon, 1991).

We have already argued that the scientific enterprise is a social enterprise, and that scientific knowledge is conjectural, going beyond the data; the research questions for this study relate to the ways in which young people represent scientific knowledge and the scientific enterprise.

There are important distinctions to be made between representations of *the scientific enterprise*, representations of *scientific knowledge* and representations of *personal knowledge*. We are interested in students' representations of *the scientific enterprise* : what domains do they think scientists attempt to explain, and on what basis do they think that scientists make knowledge claims? One might speculate that students interpret scientific activity through a variety of common cultural representations of science in the media and in school science teaching; it is certainly unlikely that school age students have any direct experience of the workings of the

scientific community to draw upon. The nature of these representations amongst students, and the ways in which they change between the ages of 9 and 16, is the main focus of enquiry of this study.

Direct probing of students' representations of aspects of the scientific enterprise is problematic, in that school students have no real opportunity to participate in the scientific enterprise; in most cases contact with science is through school science lessons. At some time in most students' lives, however, they are likely to encounter information about particular scientific communities, whether this is through the media, through school science or through particular professional or personal circumstances in adult life (Layton et al., 1993). At this stage, representations of the knowledge produced by scientific communities may be constructed. We felt it reasonable to assume that a knowledge of how students represent scientific activity *as encountered in school science contexts* (i.e.their *personal knowledge*) would be insightful in hypothesising about the issues facing them in coming to representations of science as located in particular scientific communities. The second line of enquiry of the study thus relates to students' representations of scientific activity in familiar school science contexts.

The final line of enquiry relates to students' representations of the processes through which scientists come to make knowledge claims. There is no reason to assume that students in the 9 to 16 age range will have detailed knowledge of the workings of particular scientific communities: their knowledge is more likely to be based on fairly superficial treatment of the subject in the science curriculum, combined with common cultural representations of scientists. The point of interest is therefore the ways in which students come to represent the social processes of scientific communities, when introduced to descriptions of the workings of such communities.

In this paper, the phrase 'the nature of science' is thus used as a shorthand for these three lines of enquiry: (i) the domains and purposes of scientific activity; (ii) the nature of the basis on which scientific knowledge claims are made; and (iii) the nature of the personal and social processes through which scientists establish knowledge claims.

Previous research on students' understanding of 'the nature of science'

A major study investigating the nature of young people's representations of the domains of interest of scientists in their work has been carried out by Aikenhead *et al.* (1987). A written survey instrument was used with a large sample of Canadian high school graduates (aged 16 to 20), independently from any teaching programme. A main finding of the study is that students tend to characterise the purpose of science as being the manufacture of artifacts, usually for the enhanced wellbeing of Humankind. When the generation of explanations is mentioned as a purpose for science, these are often seen as simple mechanistic explanations, rather than more general explanatory theories. It is also reported that the conjectural nature of scientific theories tends not to be appreciated by students. Rather, they tend to view theories as emerging from observed features with changes in scientists' theories over time coming about through improvements in instrumentation (e.g. more powerful telescopes). Carey (1989), Songer and Linn (1991) and Larochelle and Désautels (1989) have reported similar views about the epistemology of scientific knowledge amongst students in the secondary years, in the context of theories encountered in their own learning of science.

Young people's representations of scientific knowledge, and in particular the relationship between theory and evidence in scientific enquiry, have been investigated by both psychologists and science educators. In a classic study to describe differences between how very young children and older children use theories as tools in solving problems, Karmiloff-Smith and Inhelder (1974) noted a tendency for older children to gather evidence systematically from a theory, and to evaluate the theory in the light of such evidence. They suggest that presenting children with counterexamples did not in itself produce change in students' ability to relate theory and evidence, a claim also made by Rowell and Dawson (1983) in the context of a study

on the use of counterexamples to promote conceptual change in the context of explanations of floating and sinking. In addition, Rowell and Dawson noted that young people's *espoused* views about how they tackle problems involving theory and evidence, and the *actual procedures that are used*, are different.

A number of studies address the question of whether differences between younger and older students' ability to relate theory and evidence can be accounted for in terms of the development of general reasoning skills, or an increased ability to deploy particular reasoning strategies in certain contexts. Kuhn *et al.* (1988) describe a number of experiments where children and adults evaluate 'theories' in terms of particular data items. The theories that the students were asked to evaluate in this study were set in everyday contexts and were independent of scientific subject matter. The authors note an increased tendency for older students to think about theories and the evidence that relates to them as separate entities, and they account for this in terms of the development of general reasoning skills.

This explanation is, however, questioned by Samarapungavan (1991). She presents evidence that children as young as 6 years old are able to *differentiate* theories on the grounds of logical and empirical consistency, generalisability, and parsimony; caution should therefore be exercised in concluding that younger and older children have different capabilities for logical thinking.

No work has been identified focusing on the ways in which young people represent the processes through which scientists come to make knowledge claims.

Elicitation of students' representations of 'the nature of science': methodological considerations

A number of different approaches to eliciting students' representations of 'the nature of science' have been identified. The first approach is to ask a direct question such as 'Why do you think that scientists do experiments?' (Solomon et al., 1993), or 'What does it mean to study something scientifically?' (Durant et al., 1989). The problem with this approach is in interpreting responses. Students could answer with any one of a variety of 'scientists' in mind, and these may not be made explicit to the researcher. Similarly, the word 'experiment' may be used with a variety of different meanings (Leach et al., 1993a). Scientists do, of course, do 'experiments' for a number of different reasons.

Alternatively, an ethnographic approach could be used. Young people could be observed while engaged in various activities as part of their school science learning, and inferences could be made about the representations of the domains of science or scientific knowledge which guide their actions. The problem with this approach is that the representations of the domains of science or the nature of scientific knowledge which guide young people's actions in the context of their own learning of science may not be the same as their representations of the domains in which scientists work or the nature of knowledge generated by scientists. For example, young people engaged in investigative work in school may well be aware that the purpose of the activity is to 'discover' the answer that the teacher will reveal at the end of the lesson - there is no reason to assume that they think of scientists' work in a similar way.

A third, intermediate approach involves designing tasks to be completed by young people, and then asking them to elaborate upon their actions and responses to questions in the context of the activity. The advantage of this approach is that researchers can select appropriate contexts for their interests, rather than waiting for these to arise in the classroom. Similarly, the context in which young people's representations apply is clearer than if a decontextualised question is asked. For these reasons this third approach has been used in this study.

As has been stated, we are interested in students' representations of the domains of science and the nature of scientific knowledge in the context of the work of scientists. We realise, however,

that for most students in the 9 to 16 age range it is more likely that they will answer in terms of their own experiences of science from school and other cultural sources, than in terms of the work of scientists. In designing tasks on which students could talk about their representations of the domains and nature of scientific knowledge, it was necessary to identify conceptually rich contexts with which students are familiar, similar to those encountered by students in their learning of science, rather than the more generalised correlational hypotheses used by Kuhn *et al.* (1988). A number of contexts were trialled with students in the 9 to 16 age range. During these trials, we noted that pairs of students used talk to understand conceptual features of the context, and were therefore much better at addressing more complex metacognitive questions about the domains and nature of scientific knowledge, than individuals. Interviews were therefore carried out with pairs throughout the study. (There are still, however, cases where students' abilities to address the metacognitive questions of the probes are constrained by their conceptual understanding of the context.)

In this way, diagnostic instruments (termed 'probes') were designed so that each aspect of interest could be addressed in more than one context. Seven probes were designed for administration as interviews with pairs of students at ages 9, 12 and 16.

A further probe, addressing the processes through which scientists produce knowledge, was administered to whole classes of 16 year olds working in groups of four. This probe was administered as a whole class activity in order that students could be introduced to the workings of particular scientific communities, prior to carrying out activities through which we could make inferences about their representations of the processes through which these communities made decisions. It was not possible to administer this probe at ages 9 and 12 due to the level of background knowledge required by students.

Appendix 1 contains a description of the tasks, together with information about sample size.

The design and administration of one probe, the Scientific Questions probe, will now be described, together with some preliminary results. Further details of the Scientific Questions probe can be found in Leach et al. (1993b).

The Scientific Questions probe: students' representations of the domains of science[1]

The Scientific questions probe was designed to elicit information about students' representations of the domains of science. In order to examine this, we presented students with a range of questions which they were asked to judge as questions that scientists would be interested in finding out more about ('scientific questions') or questions that scientists would not be interested in finding out more about ('not scientific questions'). We imagined that students might draw upon a number of factors in deciding whether a particular question is a scientific question. Such factors might be: the type of phenomenon that is the subject of the question; whether the question is open to empirical investigation; whether the question has strong associations with school science; or the amount of background theoretical knowledge required to address the question. A set of questions was drawn up which spanned these dimensions (see Appendix 3). The questions are diverse in that answering some required empirical evaluation, whereas others are not amenable to empirical enquiry at all. Some questions assume a high level of background knowledge on the part of the person answering the question whereas others do not. The domains of the questions include natural phenomena, as well as social, ethical and economic issues. By presenting these questions to students and finding out whether they see them as 'scientific questions', inferences can be made about the ways in which young people of different ages construe and demarcate science as a domain of knowledge.

Young people were interviewed in pairs. They were presented with the questions written on

[1] The reasons for our interest in various features of students' representations of 'the nature of science' have already been described; appendix 2 provides further information about these features.

individual cards. They were asked to consider the question on each card and to say whether they thought it was a scientific question, not a scientific question or whether they were not sure. They were told that scientific questions are questions that scientists might want to find out more about. They were then asked to explain the reasons for their classification. The interviewer asked students to choose any scientific questions that they thought might be particularly interesting to scientists, and to explain their reasons.

ANALYSIS

Students' responses were coded at a number of levels. At the first level, a record was made as to whether each question was classified as a scientific question, not a scientific question or the students were not sure. In practice, a variety of justifications for these classifications were made by students, and the second level of coding aimed to group similar justifications. The third level of coding aimed to draw together features of responses across the different questions. What differences did students note between the questions? What features of the questions were used in classifying as scientific questions or not scientific questions? Were these features used consistently across the questions? The same coding scheme was used across each of the questions. The major part of the analysis focused on students' justifications for classifying particular questions as scientific questions, not scientific questions or not sure. The justifications offered by students tended to focus upon three features, but at varying levels of specificity:

- Whether the question is open to investigation;
- The domain of the phenomenon in question; and
- The personal and institutional characteristics and interests of scientists.

Coding categories, derived from these features of responses, were not treated as mutually exclusive; responses which referred to both the testability and the conceptual domain of the question received two codes. The coding sets for each of these features are given in appendix 4.

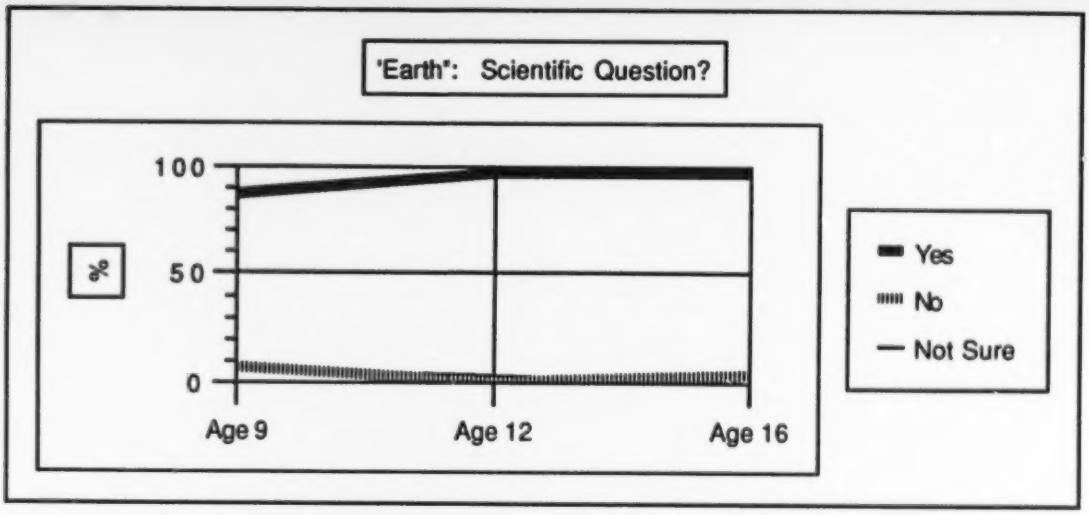
At the end of the interview students were asked what factors, in general, make a question a scientific question. Analysis was designed to determine whether criteria were used consistently, and whether this changed with age.

A number of different representations of the nature of empirical testing required to answer the question, the domain of the question, and the personal and institutional characteristics of scientists, were noted in the study. These will be illustrated by considering two of the questions, 'How was the Earth made?' and 'Which is the best diet to keep babies healthy?'.

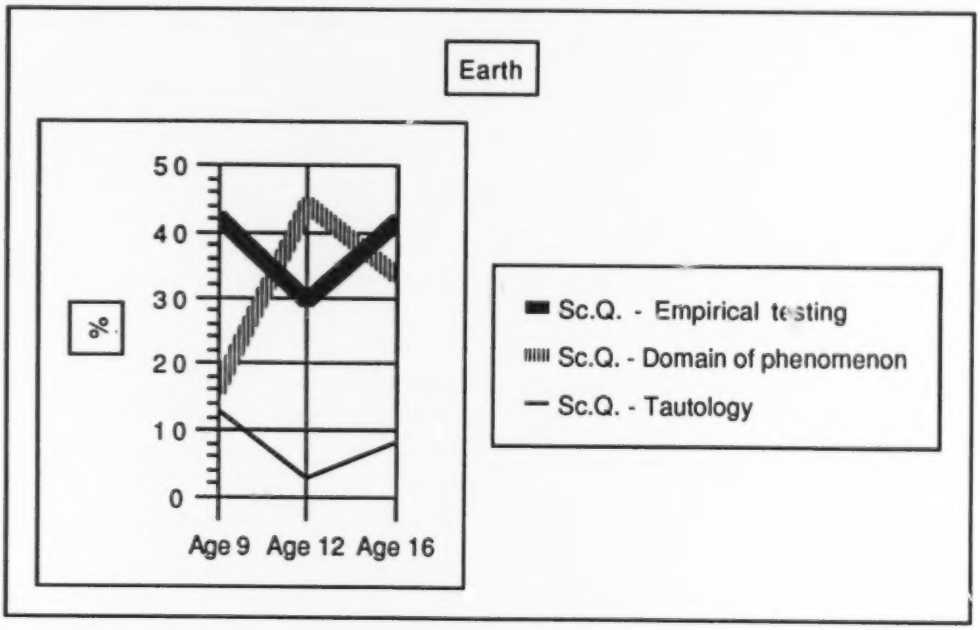
RESULTS

How was the Earth made?

This question was almost unanimously classified as a scientific question at all ages:



The percentages of responses referring to empirical testing and the domain of the phenomenon are shown in the following graph:



At all ages, there was a tendency to offer a tautologous justification for classifying this as a scientific question. Subjects seemed so convinced that this is a scientific question that justification seemed irrelevant:

I *How was the earth made? Why are they interested in that?*
P *They want to find out how it was made and what it's made out of.*

(Age 16)

There are interesting age-related trends in the ways in which subjects referred to both empirical testing and the domain of the phenomenon.

Justifications relating to empirical testing

At each age, a number of responses referred to an unproblematic process of finding out how the world really was made (coded 'test if it happens'):

I *How was the earth made?*
P *Well no-one's sure really are they, so people are always trying to find out.*

(Age 16; test if it happens)

At ages 9 and 12, a small number of responses suggested that scientists would be interested in this question because there is a process of making something involved (coded 'make a phenomenon happen'):

I *What made you decide that scientists would be interested in finding an answer to that question?*
P *Well, they're trying to build a planet on Mars, because people think there was life on Mars years ago, and they might want to try and make it the planet that can live again, 'cause I've watched this programme and they want to see if they can put life on it again with special ways.*

(Age 9; make a phenomenon happen, or stop it)

By ages 12 and 16 a number of more sophisticated responses about the nature of empirical testing were noted. A number of responses suggested that scientists would be interested in comparing *mechanisms* for how the Earth was made, to evaluate a theory (coded 'evaluate a theory'). Similarly, some subjects suggested that although the question is unanswerable, information from various sources could be used to compare theories (coded 'find a cause'):

P1 *Yeah, well there's loads of theories to that. I mean, so called the 'big bang' and it could have just been one planet exploding, right. The core being sunk, 'cause that's meant to be the hottest part and then like just bits got in orbit round it and that slowly formed into planets.*
I *And what makes that something that scientists .....?*
P1 *Well, yeah, because nobody actually knows how the earth was made. And everybody tries to think out why the dinosaurs with us. I mean, they all say that some big meteor hit the earth and span it round the wrong way and that's what killed everything.*
I *Okay. Do you want to add anything to that?*
P2 *Yeah. They're still looking for evidence in everything. You know, like digging up things. Fossils and everything. Looking for special marks. It's got something to do with science.*

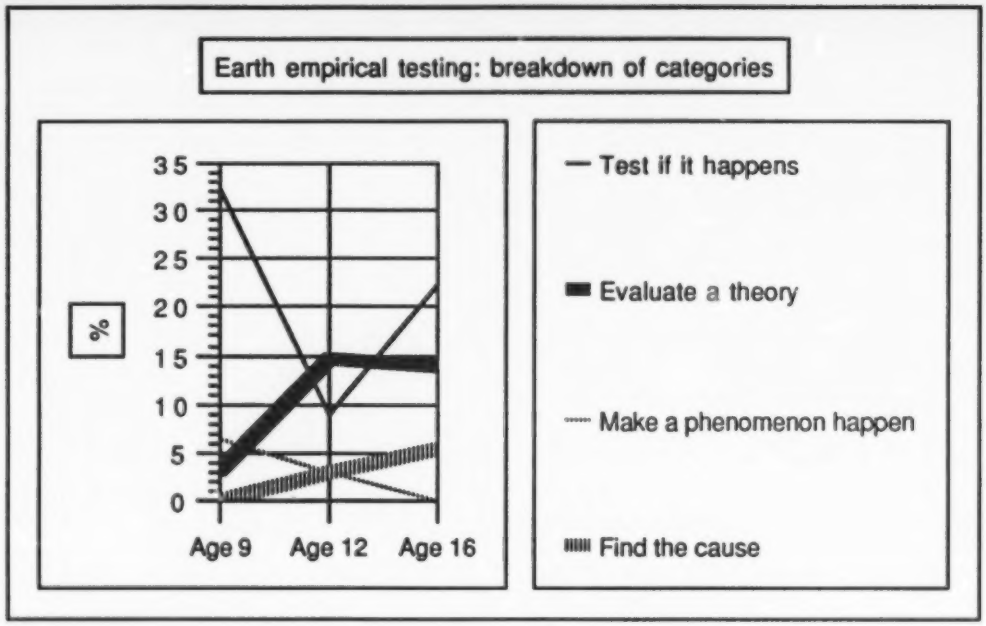
(Age 16; evaluate a theory)

I *But what makes it a scientific point of view?*
P *When you look into the crust and all the different parts of what it's made up and Bronze Age, and Iron Age and all that and all the chemicals and minerals and what made the Earth and everything.*
I *Okay. What it's made out of and history.*
P2 *That sort of thing. Yeah, I should think would be scientific.*

(Age 16; find the cause)

In general, there was hardly any reference to the difficulties of collecting empirical evidence for a process that has already happened.

The percentages of responses at each age using these forms of reasoning are shown in the following graph:



There is an increase in the representations of empirical testing as being theory-based (i.e. 'evaluate a theory' and 'find the cause') with age.

Justifications relating to the domain of the phenomenon

In referring to the domain of the phenomenon, subjects referred to improving the quality of life by stopping polluting the Earth (coded 'quality of life'), a general interest amongst people in the history of their planet (coded 'social interest'), and the fact that the domain of the phenomenon is about the Earth (coded 'nature of the phenomenon'):

I *And why are scientists interested in something like the Earth do you think?*
P *Because of pollution destroying it.*

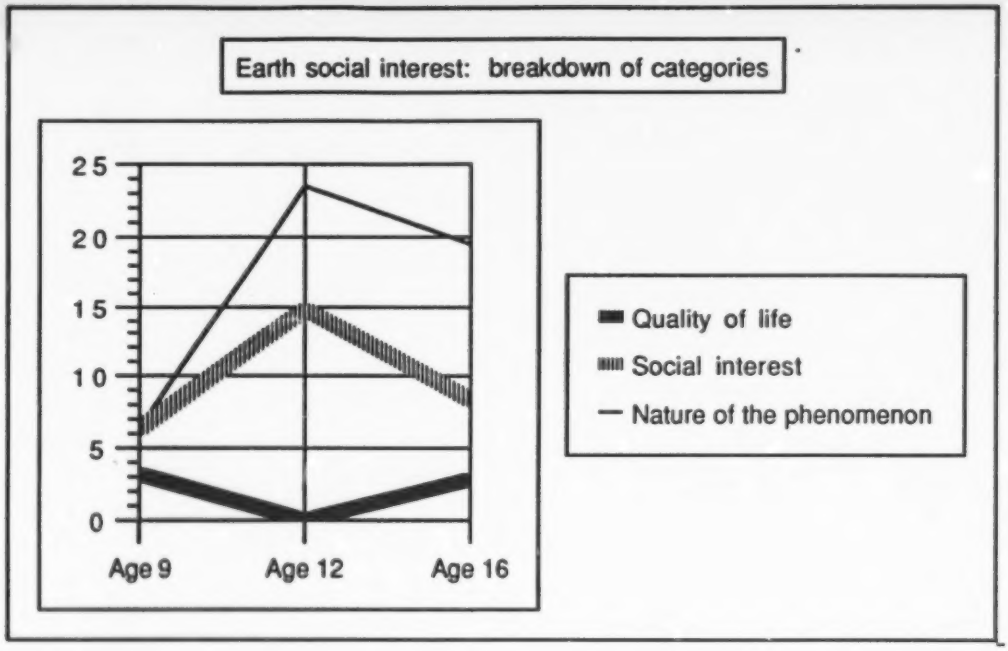
(Age 9; quality of life)

I *Why would they be interested in that question?*
P *Because they would want to know how it was made and that and people would want to know.*

(Age 9; social interest)

P *I don't know really. I just think it'd be interesting how you'd how you know your own planet had been made.*

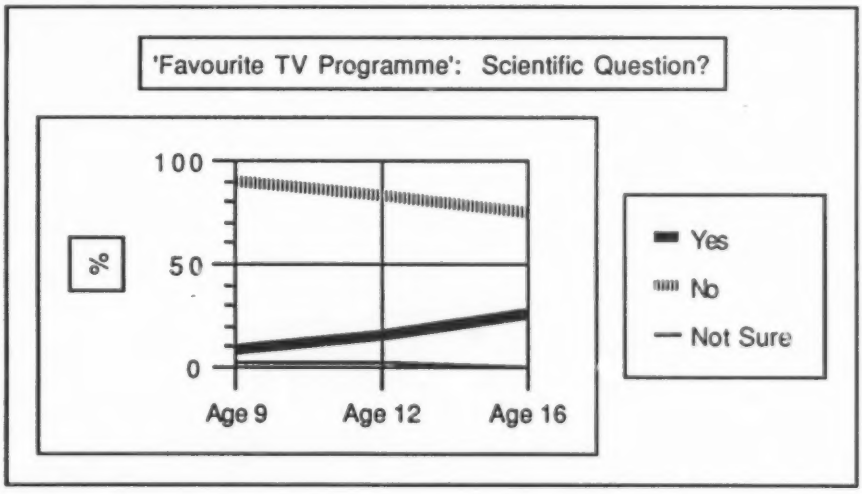
(Age 9; nature of the phenomenon)



The apparent decline between ages 12 and 16 in references to the quality of life, social interest, and the nature of the phenomenon are due to an increased number of responses referring to empirical testing.

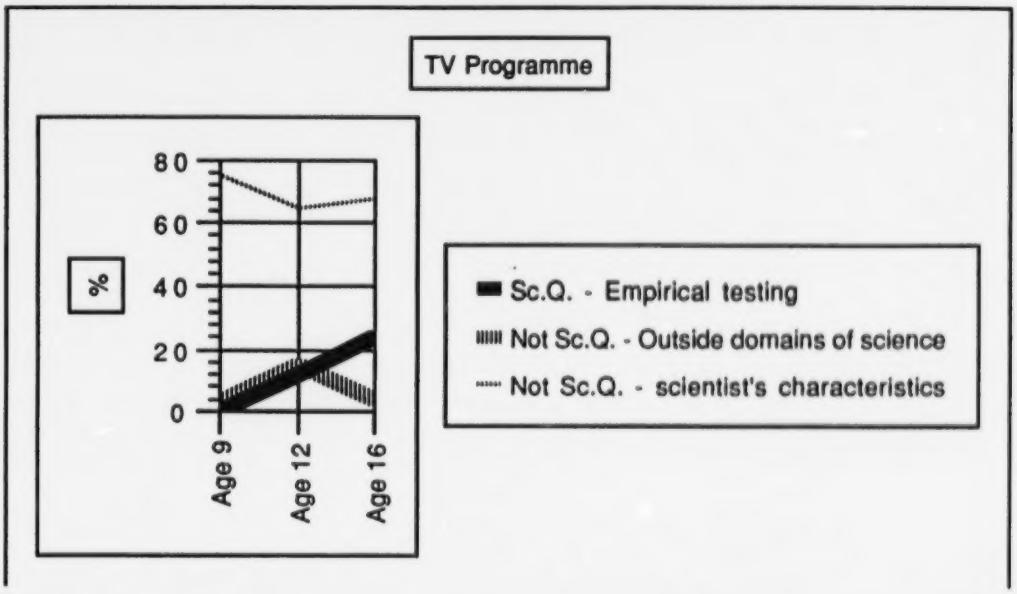
Which is the best programme on TV?

The majority of subjects at each age suggested that this question would not be of interest to scientists, as can be seen in the following graph:



There is a trend with age for more subjects to classify the question as a scientific question on the grounds that some empirical testing may be involved ($p<0.084$). Of the subjects who stated that the question is not a scientific question, the majority suggested that this is because the subject of TV programmes is outside the domains of science. A number of subjects, however, stated that this question is not empirically testable and therefore of no interest to scientists. The percentage

of responses at each age referring to each of these features is shown in the following graph:

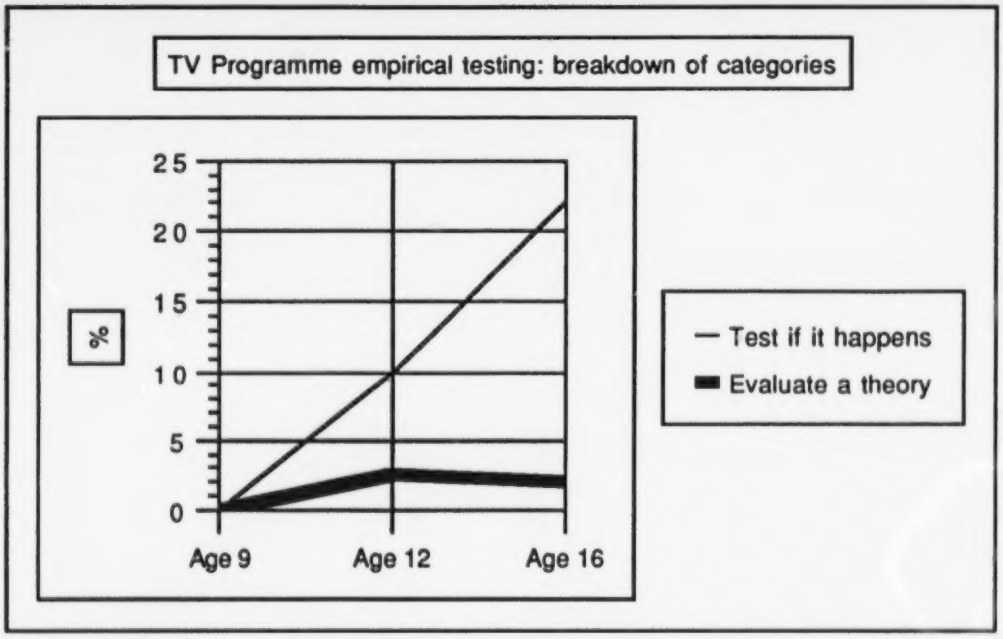


Justifications relating to empirical testing
There are interesting trends in the ways in which subjects at different ages referred to empirical testing. Typically, at age 9 empirical testing was not mentioned. At ages 12 and 16 many responses suggested that it is possible to test empirically which TV programmes are the most popular (coded 'test if it happens').

A small number of responses at ages 12 and 16 suggested a rather more sophisticated notion of empirical testing, involving the need to operationalise some of the terms in the question such as 'best' (coded 'evaluate a theory'). Once these terms have been defined, then scientists can investigate which is the 'best' programme on TV:

P1 *The best programme on TV, just about everybody has got a different favourite programme, so ...*
(...)
P2 *But they do it and find out the most popular, yeah but, they don't find out the 'best'.*
I *Oh I see. How would they find out the most popular?*
P1 *It would just be averages. They ask about 100 people and work out a percentage.*
(Age 12)

The following graph illustrates the percentage of such responses at each age:



The increase with age in the number of subjects suggesting that the question is empirically testable is significant ($p<0.062$).

Justifications relating to personal and individual characteristics
As well as mentioning empirical testing, a number of responses referred to the personal and institutional characteristics of scientists in classifying this question as a scientific question or not. A number of subjects suggested that scientists have no particular expertise to bring to bear on this matter (coded 'no special expertise'). Others suggested that the best TV programme is simply a matter of opinion (coded 'matter of opinion'):

P *It's like a question you get in a magazine. It's a matter of interest really. It's nothing really important.*

(Age 16; no particular expertise)

P *Well that's to do with people's opinions it's not and you can't really say what's best and what ... it just depends on your opinion.*

(Age 16; a matter of opinion)

It is interesting to note that many such responses suggested that scientists are not interested in things that are a matter of opinion and therefore likely to change, but rather in phenomena that are predictable and lawful.

A number of responses referred to the personal characteristics of individual scientists. At age 9, many subjects seemed to draw upon a stereotyped image of scientists as people who would not watch the TV (coded 'stereotyped scientist'). No distinction was made between the personal interests of scientists and their professional activity, and it was concluded that scientists would not be interested in this question. Following similar lines, a number of responses suggested that scientists may have a personal interest in TV programmes, and may therefore investigate this question (coded 'personal motivation'):

I *Okay. So what is it about that that you think scientists wouldn't be interested in.*
P1 *Because they don't watch telly much and there would just be some boring programmes and things like that, and they wouldn't really be interested in programmes*

and TV.

(Age 9; stereotyped scientist)

I *What was it about this one that made you decide that it was a scientific question? A question that scientists would want to find out more about?*
P1 *'Cos there's quite a lot of good films on. (...)*
P2 *And good programmes.*

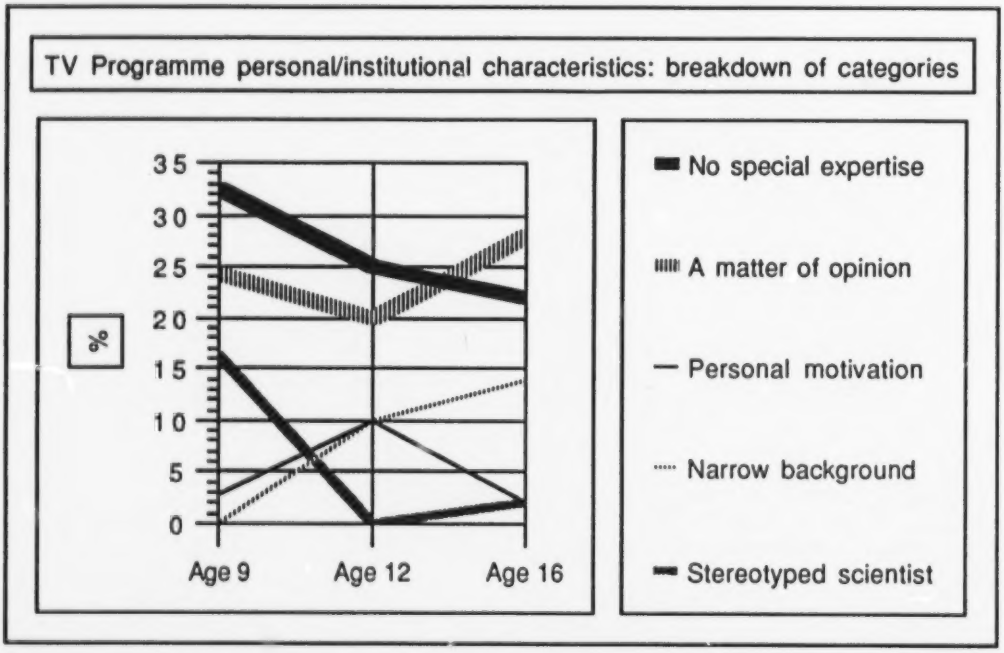
(Age 9; personal motivation)

A number of older subjects suggested that even though this question is open to empirical investigation, the investigators would not be scientists (coded 'narrow background'); companies would employ other people to do this sort of work:

I *Yeah. Which is the best programme on TV?*
P *Oh that's a matter of opinion and it's [pause] erm sort of it'd have to be carried out by market research. Erm it's not really scientific at all.*

(Age 16; narrow background)

The following graph shows the percentages of such responses at each age:



There is a change with age in the way in which subjects draw upon the personal characteristics of scientists. At age 9, a stereotyped view of the scientist as someone uninterested in 'worldly' matters such as TV programmes seems to prevail. At age 12 this view was not noted, though a number of responses seemed to suggest that scientists' work is governed by their everyday interest in matters such as TV programmes. By age 16, there was little mention of the personal characteristics of scientists.

There is a significant increase in the number of subjects referring to different professional groups carrying out market research work on favourite TV programmes ($p<0.062$).

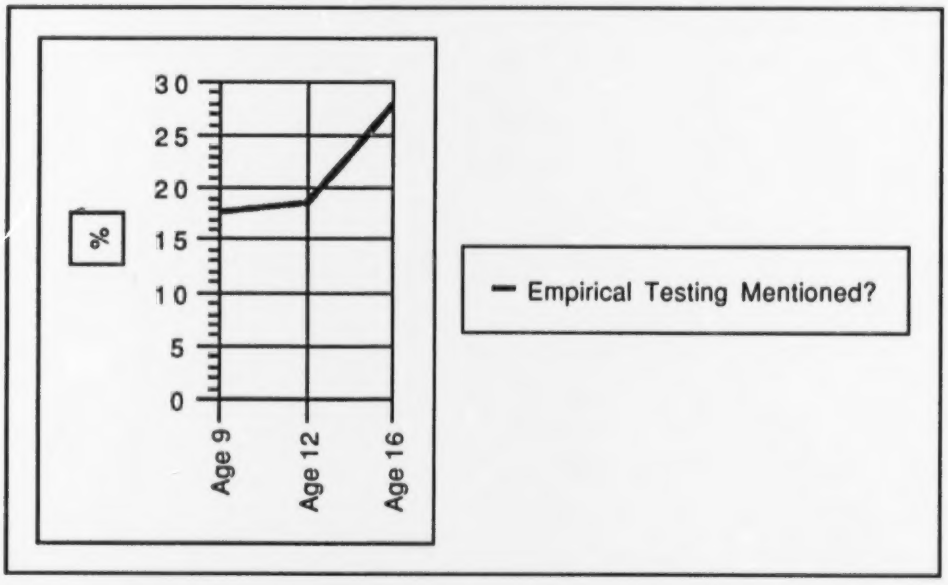
AGE-RELATED CHANGES IN REPRESENTATIONS OF THE DOMAINS OF SCIENCE

As has been described, the questions presented to students differed significantly in context and amenability to empirical investigation. Not surprisingly, students justified their classifications of these questions according to different criteria; age-related changes in types of justifications do not necessarily occur across the full range of questions. Nonetheless, it is possible to identify some changes that seem to occur in students' representations across a number of the questions.

In general, older subjects tended to offer more detailed justifications which drew upon a wider range of factors, than younger subjects. We did not note a tendency amongst subjects of any age to use criteria consistently across contexts: the tendency was to address each question as a separate case. At the end of the process of justifying each question as a scientific question or not a scientific question, subjects were asked what, in general, makes questions scientific questions. Their answers tended to refer to specific features of the individual questions, rather than making a more general analysis.

RESPONSES REFERRING TO EMPIRICAL INVESTIGATION

In general, older subjects were more likely to refer to empirical testability as a criterion for scientific questions, than younger pupils ($p<0.0008$ across the six reported contexts), as shown in the following graph:



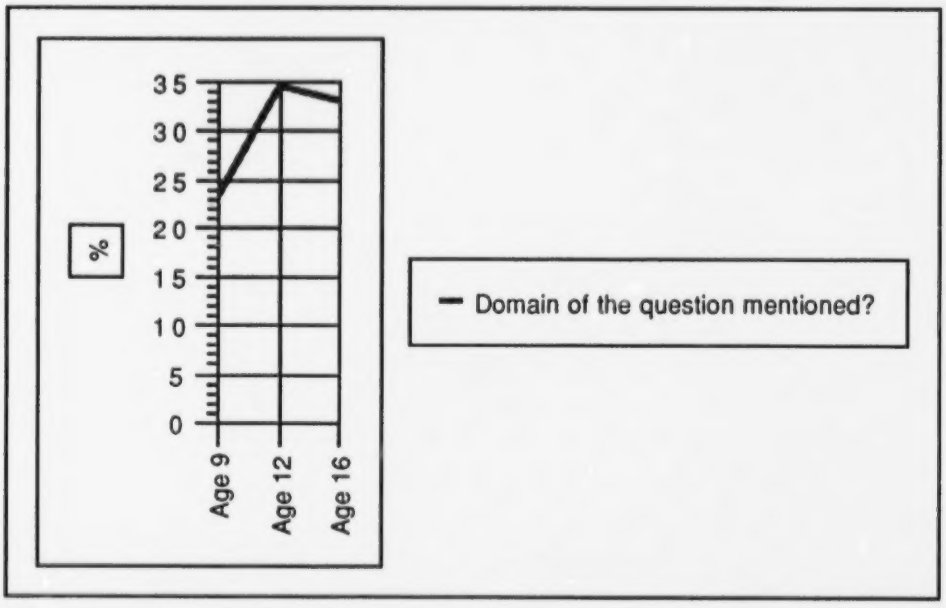
In all cases, but particularly the cases of the Earth and Atmosphere questions, there are clear differences in the ways in which younger and older subjects referred to empirical testing. Typically, younger students referred to an unproblematic process of finding out whether something really does happen, with little consideration of how this could be done in practice. By contrast, older subjects sometimes referred to a view that particular questions cannot be operationalised for empirical investigation, and are not, therefore, scientific questions. When older subjects did refer to empirical investigation, this was often more sophisticated in nature and suggesting a need for knowledge of mechanisms rather than simply finding out whether something happens. For example, some older subjects suggested that in order to *stop* global warming it is necessary to know the *cause* global warming as well as *whether it is happening*. In a small number of cases, subjects referred explicitly to an empirical process of data collection in order to evaluate a theory (such as a particular theory about how the Earth was made).

RESPONSES REFERRING TO THE DOMAIN OF THE QUESTION

A wide range of different responses mentioned the domain of the question. There was a strong tendency to classify questions seen as having particular significance to human beings (such as Atmosphere and Babies) as scientific questions. Many older subjects drew upon their knowledge of subjects in the school curriculum to classify questions as scientific, though in some cases the responses of older students suggested a more sophisticated view that scientists are interested in predictable natural phenomena rather than matters of public opinion. In the case of the Dolphins question, two responses stated that the question was ethical rather than scientific.

When discussing the two possible explanations for the 'mystery' of whether talking to plants makes them grow better, older subjects tended to refer to whether they could see a possible mechanism in deciding whether scientists would be interested in the explanation. For example, the process of photosynthesis was often mentioned as a reason why scientists might investigate whether something from the breath affects plant growth.

Between the ages of 9 and 12, significantly more responses refer to the domain of the question in justifying classifications ($p<0.0028$):



RESPONSES RELATING TO VIEWS OF THE PERSONAL AND INSTITUTIONAL CHARACTERISTICS AND INTERESTS OF SCIENTISTS

Again, a wide range of responses referred to the personal and institutional characteristics and interests of scientists. Although there is no age-related trend in the frequency of mention of the personal and institutional characteristics and interests of scientists, the representations of scientists used by younger and older students do differ. Typically, younger pupils did not differentiate the personal and professional interests of scientists, suggesting that as scientists are male and serious they would not be interested in babies' diet or TV programmes. In many cases older subjects showed a more sophisticated knowledge of the types of professionals employed to do various tasks, stating that market researchers, rather than scientists, would carry out particular forms of empirical testing.

OTHER RESPONSES

At age 9, a significant number of responses did not justify their classification in any way, other than by answering the question. Similarly, a number of younger subjects used tautologous reasoning, stating that certain questions are scientific 'because scientists would be interested in it'. This tendency seems to decline between age 9 and 12 ($p<0.016$ across the six reported contexts), though this could be explained by the possibility that 9 year olds were less likely to understand our questions that 12 year olds, and therefore fell back upon tautologous reasoning.

The notion of 'progression in learning science'

In investigating progression in children's learning of science we have identified a number of different approaches to studying the general question of progression each addressing different facets of the problem.

A commonly adopted strategy (and one used in the classical studies by Piaget and his collaborators) is that of mapping trends in the responses of children of different ages to the same task within the domain of interest. Such cross-age studies have enabled characterisations of students' reasoning in particular science domains to be identified and gross changes with age to be described. Research carried out into children's conceptions about the physical properties of air is an example of such a study (Brook and Driver, 1989). In this case it was noted that students aged 5-7 did not view air as substantive but by age 8 most students acknowledged the existence of air as taking up space. Between ages 8 and 12, however, they tend to consider air as having negative weight or to be weightless. The conception of air as occupying space and having mass and weight evolves during the secondary school years (maybe as a result of teaching). Such a study enables different representations to be identified and gives patterns of prevalence in children's reasoning at different ages. We see such studies as being useful in planning curriculum activities and materials appropriate to different age groups of children, as well as informing teaching interventions at particular ages. We view the present study as being of this type.

Such cross-age studies do not, however, address the issue of individual trajectories in learning. A longitudinal design is necessary for this. By following the same students over time a series of 'snap-shots' can be obtained to characterise individual learning trajectories. Questions such as the extent to which learners follow similar or different trajectories or the influence of particular instructional materials on learning trajectories can then be investigated. Such studies can also provide an empirical reference point for theorising about how conceptual change is characterised: is it a process of theory change as suggested by some scholars (e.g. Vosniadou and Brewer, 1992; McClosky, 1983) or does it involve piecemeal and parallel developments (e.g. Solomon, 1983)?

Such longitudinal studies can yield greater 'fine structure' in the routes individuals take in their learning. However, they still only provide a description of the route taken in learning. They do not provide information about the dynamics of the processes which 'drive' progression. For this, appeals need to be made to theories of learning. The current interest in theories of learning as conceptual change is one such approach to studying this problem.

Learning science - what progresses?

Different perspectives on learning science place differing emphasis on changes in various features as learning takes place, including individual cognitive changes (Carey, 1985; Kuhn, 1988; Chi, 1992; Vosniadou and Brewer, 1992), socially mediated changes (Bruner, 1985) and attitudinal changes (Pintrich et al., 1993). We view learning science as a process of enculturation where learners are encultured into scientific ways of knowing through social processes, making personal sense of scientific representations of phenomena in terms of their existing 'everyday knowledge' (Driver et al., in press).

Everyday ways of representing natural phenomena differ from scientific representations in terms of both their epistemology (the purposes and status of explanations) and ontology (the entities from which explanations are constructed). For example, many everyday representations are grounded in very narrow contexts: when describing a fire burning down 'to nothing' the aim is to produce an explanation specific to the context of burning fires, possibly with the pragmatic purpose of describing how much fuel is used and how much solid waste is left. The epistemological commitment of such everyday representations is to successful explanations in particular contexts. By contrast, a scientific explanation of the process of burning is grounded in a theory of chemical change: the main epistemological commitment is to produce generalisable, reliable explanations. Similarly, the ontology of everyday and scientific representations of burning differ in that everyday representations do not take account of gaseous products: the fire has burnt 'to nothing'.

A large research literature now exists on children's representations of natural phenomena and how these change with age (see Carmichael et al., 1990). From these studies, it is possible to make inferences about the nature of children's 'everyday ontologies'. For example, when a log fire burns down to a pile of ash, children state that matter is 'burnt away' (Andersson, 1991). Although older children may acknowledge that there are gaseous products, these are not viewed as 'substantive matter' having properties such as mass (Meheut et al., 1985). Similar findings about children's representations of gases have been found in other physical and biological contexts (Stavy, 1990; Brook and Driver, 1989; Leach et al., in press (a)).

By contrast, there have been fewer studies of the epistemology of children's everyday knowledge and how this changes with age. This study is being undertaken to contribute to this field.

To be successful in learning science, children may have to construct new ontological entities (such as 'matter') as well as learning about the epistemology of scientific knowledge and how this differs from the epistemology of everyday knowledge. It is likely that progression in *conceptual understanding* of science involves an interaction between these features (Leach et al, in press(b)).

Uses of data from cross-sectional studies

It is intended that this study, along with studies of conceptual trajectories of learners in particular conceptual domains, will help to provide a 'map' of progression in science learning across the school years. In turn, this can be used to inform intervention studies designed to promote learning, and curriculum design and sequencing (Driver, Leach, Scott and Wood-Robinson, in preparation).

It appears that progression in conceptual understanding of science involves complex, interacting changes in:

- the ways in which learners come to represent features of 'the nature of science' such as the nature of scientific knowledge and the domains of science;
- the representations of particular phenomena available to learners; and
- learners' background knowledge about the characteristics of scientists and the institutional norms of the scientific enterprise.

Other features, such as changes in motivation to learn science, are also likely to be important.

It is not possible to describe *individual* trajectories in learning from cross-sectional studies. Cross-sectional studies do not give information about what children at particular ages *can* do, but rather what they *do* do in a given situation. For example, it is not valid to conclude that just because certain 9 year old students did not refer to empirical testability, or conceptualised the nature of the empirical testing required for a particular scientific question in a non-standard way, they were not *capable* of such references or conceptualisations. One the one had, it is possible

that 9 year old students are not able to think about theories as separate from the evidence that they attempt to explain, but on the other hand it could be that 9 year olds are not clear as to what mode of response is appropriate in the particular social setting of the interview or the science classroom. Such questions about the underlying basis for progression cannot be answered through cross-sectional studies.

Data from studies such as this one can, however, be used to inform teaching interventions by highlighting possible mismatches between student representations of 'the nature of science' and the views underpinning the curriculum. For example, in the UK many science teachers use 'practical work' of various kinds as illustration for (or even 'proof' of) particular conceptual representations, with lower secondary school students. This research suggests that a number of such students may well think that the purpose of such work is to find out whether particular phenomena really do happen rather than to explain them. It may therefore be prudent for teachers to spend more time in making explicit the purposes of such activities.

Similarly, information about prevalent student representations of 'the nature of science' at different ages can be used to inform the sequence in which particular aspects of 'the nature of science' are introduced into the curriculum (Driver et al., in preparation).

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APPENDIX 1: PROBES USED AND SAMPLE SIZE

Task Name, and Aspect	Focus of task	Description of task
Experiment *Nature of scientific knowledge*	Inferences are made about pupil's understanding of the word 'experiment' and their ideas about the relationship between theory and evidence in experiments.	Pupils classify descriptions of people engaged in various activities as 'experiment', 'not experiment' or 'not sure', giving reasons. 30 pairs at ages 9, 12 and 16.
Belief *Nature of scientific knowledge*	Inferences are made about the warrants seen as necessary for belief by pupils, and the status of theories.	Pupils are asked for their warrants for belief for specified commonly accepted theories about the shape of the Earth and the flow of electric current. 30 pairs at ages 9, 12 and 16.
Theory Stories *Nature of scientific knowledge*	Inferences are made about children's ideas about the status of theories and their relationship with empirical evidence.	Pupils respond to three stories in which theories are described, and asked whether characters in the story know about the basis on which the theories are true. 30 pairs at ages 9, 12 and 16.
Real and Imaginary *Nature of scientific knowledge*	Inferences are made about pupils' ideas about the status of theories, and warrants for belief in theories.	Pupils respond to three cartoons in which contrasting opinions about the status of theories are raised. 30 pairs at ages 9, 12 and 16.
Scientific Questions *Purposes of science*	Inferences are made about the role of empirical testing, and the boundaries of domains of scientific theories.	Pupils classify various questions on the basis of whether scientists might investigate the question or not. 30 pairs at ages 9, 12 and 16.
Theory and Evidence *Nature of scientific knowledge*	Inferences are made about the ability of pupils to differentiate theory from evidence, and the relationship between theory and evidence.	Pupils examine phenomena in the contexts of electricity and floating and sinking, and select theories to explain the phenomena. Empirical evidence is then presented for explanation using the theory. 30 pairs at ages 9, 12 and 16.
Plunger *Nature of scientific knowledge; purposes of science*	Inferences are made about the ways in which pupils conceptualise the processes involved in a school science activity.	Pupils watch a video of an investigation performed by 13 year old pupils in which they have to explain the phenomenon of a sink plunger 'sticking' to a surface. Pupils have to identify what they think the pupils are doing at each stage of the investigation, and why. 5 pairs of pupils at 9, 12 and 16.
Closure of Debates *Science as a social enterprise*	Inferences are made about the processes seen by pupils to influence the closure of a debate within the scientific community, and a debate on a scientific issue with broad social significance.	Pupils follow some teaching about the closure of debates within the scientific community, in the context of theories about Plate Tectonics and food irradiation. Pupils' views about the closure of debate are elicited prior to the teaching, during discussion and after teaching. Four classes of 16 year old pupils.

APPENDIX 2: MATRIX OF ASPECTS OF THE NATURE OF SCIENCE, AND KEY QUESTIONS USED IN THE STUDY

Aspect of the Nature of Science

1 Purposes of Science

The purposes of science in relation the the natural and social worlds.

2 Nature of Scientific Knowledge

The conjectural nature of theories, and the problematic application of theories to real world systems. Social, logical and empirical features in the evaluation and generation of theories.

3 Science as a Social Enterprise

The location of science in communities of people, the processes used within scientific communities to validate knowledge and the relationships between science and society.

Questions about students' representations of science

1 What are the perceived limitations on the range of questions which are addressed scientifically, and the sorts of things that scientists might be interested in working on?
2 What warrants (if any) are drawn upon by students to justify their belief/disbelief of theories? Is evidence cited, and if so is it first or second hand? Are authority sources cited and if so is perceptual evidence also used?
3 How do children interpret the emergence of conflicts in ideas within the scientific community, and the resolution of conflicts?
4 Do they see theories as imagined entities, which exist only as models (or parts of models) in the mind, and may not map directly onto anything in the real world?
5 How do children interpret the influence of society at large on the generation of scientific knowledge and the application of this knowledge in actual contexts?
6 Do children think that theories can be evaluated using empirical evidence?
7 Do children differentiate theories from the phenomena which they explain in evaluating theories with empirical evidence?
8 Are children able to evaluate theories in spite of belief/disbelief in the theory?
9 What norms do children use in evaluating theories with evidence?
10 What criteria are seen as defining the process of experimentation? What is seen as the purpose of experimentation?
11 How do children interpret the application of scientific knowledge in actual contexts that are of broader interest to society?

APPENDIX 3: QUESTIONS USED IN THE SCIENTIFIC QUESTIONS PROBE

Question:	Reason for inclusion:
Which kind of fabric is waterproof?	Can be tested empirically, little theoretical background needed
Which is the best programme on TV?	Related to aesthetics
Is it wrong to keep dolphins in captivity?	Related to ethics
How do birds find their way over long distances?	High theoretical background required to inform work.
What diet is best to keep babies healthy?	Can be tested empirically; high level of theoretical background
Is it cheaper to buy a large or a small packet of washing powder?	Related to economics
How was the Earth made?	High level of theoretical background
Is the Earth's atmosphere heating up?	Can be tested empirically; high level of theoretical background
Do ghosts haunt old houses at night?	Can be investigated empirically, but an unlikely conceptual area
What kind of bacteria are in the water supply?	Empirical testing; high level of theoretical background
Can any metal be made into a magnet?	Empirical testing, little theoretical background. School science context.

APPENDIX 4: CODING SETS USED

Empirical

a1 Does it happen?

a2 Evaluate a theory

a3 Make a phenomenon happen, or stop it

a4 Find the cause

a5 Make measurements

a6 Make predictions

Tautology

b1 Tautology

b2 Answers the question

Domain

c1 Quality of life

c2 Social interest

c3 Natural phenomena

c4 Finding out anything new

c5 School science context

c6 Historical

Personal and institutional characteristics

d1 Substantive

d2 Research programme

d3 Stereotyped scientist

d4 Personal motivation of scientists

d5 Narrow background of scientists

Not sure/other

e Not sure/other